## Selenian Boondocks

*Random Musings from the Warped Minds of Jonathan Goff, Ken Murphy, John Hare, and Kirk Sorensen*

# Mars surface shielding from radiation

Posted on September 6, 2015 by Chris Stelter

I want a short little aside here to talk about a little pet peeve of mine:
People talk as if Mars' atmosphere does basically nothing to reduce the radiation dose as compared to free space. This is definitely not true, but the confusion comes from a few areas, but largely because people have not bothered to do some basic math and geometry.

1) People use the datum or even higher altitude sites to calculate the surface pressure. The pressure at the datum (the sort of average height on Mars, analogous to "sea level," but not really) is 636 Pascals (6.36mbar http://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html ). But the scale height of Mars is 11.1km. Scale height is the constant used to determine pressure given a simple exponential model of the planetary atmosphere. The lower altitude, the higher pressure, determined by this equation:

$$P = P_0 \, e^{-\frac{z}{H}}$$

Where P is the pressure at the altitude "z", and P0 is the pressure at "zero" altitude, and H is the scale height.

So at Mars, P0 = 636Pa, H=11.1km, and the lowest point on Mars is in a corner of Hellas Basin at z=-8.2km (i.e. 8.2km below the datum), whereas pretty much all of Hellas Basin is 6km below the datum. https://www.psi.edu/epo/explorecraters/hellastour.htm

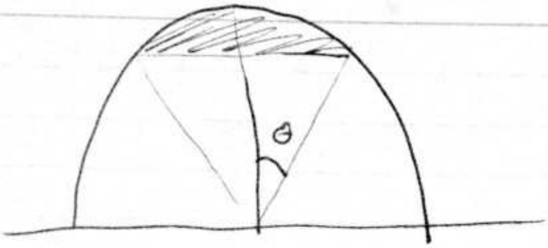
That gives us an estimate of over 1300Pa surface pressure at the deepest point ( https://www.google.com/webhp?#q=636Pa*e^(8.2/11.1) ) and at least 1090Pa anywhere inside Hellas basin ( https://www.google.com/webhp?#q=636Pa*e^(6/11.1) ).

2) People forget that Mars having a lower gravity means that the mass needed to get a certain pressure is higher than on Earth. So while 1kPa on Earth would mean just 10 grams per cm^2 of shielding, on Mars it is:
https://www.google.com/webhp?#q=636Pa*e^(8.2/11.1)/(3.71m/s^2) = 35.9g/cm^2.
https://www.google.com/webhp?#q=636Pa*e^(6/11.1)/(3.71m/s^2) = 29.4g/cm^2

3) That's already decent shielding. However, there's another significant point: That's just the shielding at the *zenith* of the sky, which is the thinnest part! Everywhere else is thicker shielding, near the horizon is MUCH more shielding.

To explain this, I tried to write out the concept of a "solid angle" and how it is relevant:

"Solid angle": area on the unit sphere




Solid angle is:

$$\Omega = 2\pi(1-\cos\theta)$$

(solid angle of a half-sphere is $2\pi$, full sphere is $4\pi$... these are the spherical analogues to 180° and 360°) (or $\pi$ radians and $2\pi$ rad)

For $\theta = 45° = \frac{\pi}{4}$ radians

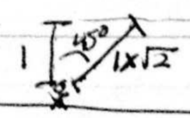
$$\Omega = 2\pi\left(1-\cos\frac{\pi}{4}\right) = 2\pi\left(1-\frac{1}{\sqrt{2}}\right)$$

$$= 2\pi \cdot .29289\ldots$$

If we divide by a hemisphere:

$$\frac{\Omega}{2\pi} = .29289\ldots \approx 29\%$$

And then:



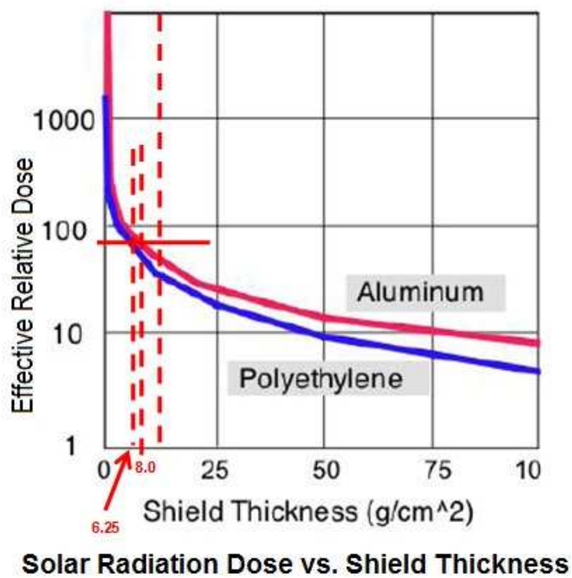

Over 70% of the Martian sky is at least $\sqrt{2}$ times thicker than the zenith.

So as you can see, the vast majority of your sky shielding (at least 70%) is over 1.4 (i.e. sqrt(2) ) times your zenith

shielding. So we can write that as:

[https://www.google.com/webhp?#q=sqrt(2)*636Pa*e^(8.2/11.1)/(3.71m/s^2)](https://www.google.com/webhp?#q=sqrt(2)*636Pa*e^(8.2/11.1)/(3.71m/s^2)) = 50.7g/cm^2
[https://www.google.com/webhp?#q=sqrt(2)*636Pa*e^(6/11.1)/(3.71m/s^2)](https://www.google.com/webhp?#q=sqrt(2)*636Pa*e^(6/11.1)/(3.71m/s^2)) = 41.6g/cm^2

So, anywhere in Hellas Basin has basically half the dose of free space (shielded by the planet itself) PLUS another at least 40 grams per square centimeter of shielding just from the atmosphere.

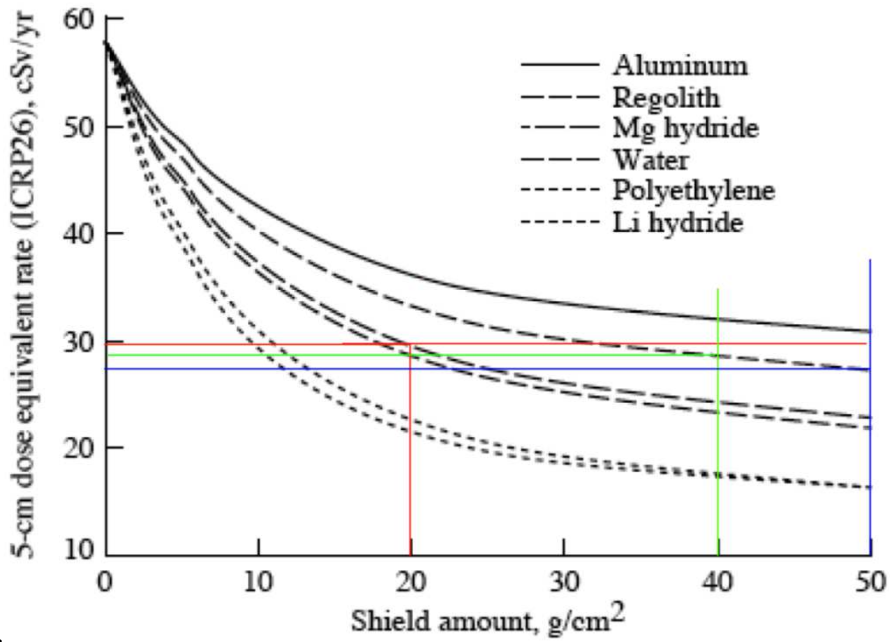



From www.buildtheenterprise.com, but I believe they took this from another paper. EDIT: Yes, it's from Rapp et al 2006

EDIT: to give an idea of how much 40 $g/cm^2$ of shielding can do here is this graph that shows roughly the attenuation capabilities of polyethylene and aluminum. Mars' atmosphere's shielding capabilities would be somewhere between those two. While this isn't quite enough to be happy from a GCR dose long-term (you'd want shielding on your hab), it does make EVAs far less dangerous in case of a solar flare (especially any acute effects), and also makes EVAs in general represent a much lower risk of long-term exposure. But the main effect is that solar flares represent a risk less than a tenth than the case without shielding (ie just the spacesuit).

(Also, as a side note: much of the northern part of Mars is far below the datum as well. Not quite 40g/cm^2 of shielding, but a solid 30-35g/cm^2 in many places… But there are MANY reasons why you might want to build your settlement at low altitude anyway.)

EDIT AGAIN, 2015-09-08:
Here is a graph from [Rapp et al 2006](Rapp et al 2006) which I've drawn roughly where the equivalent dose of 20 cm of water shielding would be for Hellas Basin's >40g/cm^2 of CO2 shielding. I added the red horizontal line for 20cm of water, looks to be just under 30cSv/year (I believe this is in open space, not on Mars), the green line is for 40g/cm^2 of regolith, which is a worst case for CO2 (carbon has lower atomic mass than the typical silicon, calcium, and aluminum that make up the balance of regolith besides oxygen) at about 28cSv, and 50g/cm^2 CO2 (deepest spot on Mars) with 27cSv or so for GCR annual dose. But again, this is free space. Those are just rough numbers, so that's a bit of false precision there, but it does show that Hellas Basin has about as much equivalent




shielding as a foot of water.

(caption: "Figure 1. Point estimates of 5-cm depth dose for GCR at Solar Minimum as a function of areal density for various materials (figure1.jpg). (Simonsen et al. 1997)")

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**Chris Stelter**

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## 27 Responses to *Mars surface shielding from radiation*

**Hop David** *says:*

September 7, 2015 at 9:24 am

So 17 g/cm^2 zenith shielding for most of Mars. Only 2 or 3 grams per square centimeter at the top of Olympus Mons.

Hydrogen rich materials are desirable for shielding against GCRs. Mars atmosphere is mostly CO2 with very little hydrogen.

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**Marcel Williams** *says:*

September 7, 2015 at 10:49 am

While the martian atmosphere appears to be thick enough to stop heavy nuclei from reaching the martian surface, people would still be exposed to levels of cosmic radiation ranging from 8 Rem to 33 Rem annually during solar maximum and solar minimum conditions. Annual radiation exposure on the lunar surface ranges from 11 Rem to to 38 Rem. So the martian surface still experiences about 87% of the cosmic radiation exposure as the lunar surface.

Human colonist permanently occupying the martian surface would probably have to live in shielded habitats that reduce their levels of radiation exposure below 5 Rem per year (the maximum level of radiation exposures allowed for radiation workers on Earth).

Fortunately, there will be no shortage of shielding material on the surface of the Moon and Mars. Radiation shielded habitats on the martian surface would probably require about 2.5 meters of water or 1.5 meters of regolith to reduce interior radiation levels below 5 Rem per year during solar minimum conditions (the worse conditions).

Marcel

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**Andrew_W** *says:*
September 7, 2015 at 12:39 pm

You seem to be looking for angles to talk up your enthusiasm for Mars.

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**gbaikie** *says:*
September 7, 2015 at 7:09 pm

Live under 10 meters of water- no radiation, and swim without spacesuits.
Similar structures on Mars as one would have 5 meter underwater on Earth- though Mars has 1/3 the force of buoyancy and less pressure per 10 meter depth- can go deeper and rise up without bends.
And swimming exercise on Mars, same as swimming exercise on Earth.

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**Chris Stelter** *says:*
September 7, 2015 at 8:08 pm

I edited the post to add some context. Of course you want to shield long-term habs, but the built-in shielding reduces some of the urgency and makes solar flares far less of a threat, reducing their severity to the point that you basically won't have any noticeable acute effects like nausea (which is the chief danger in a space suit). It also reduces the radiation dose that electronics receive, allowing you to use the same electronics that are used in LEO (which in many cases is just regular electronics but with some added watchdog circuits or redundancy and error correction).

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**DougSpace** *says:*
September 8, 2015 at 8:25 am

You made some very good points that I have not read elsewhere.

I just take the radiation levels measured on the Moon and Mars. MSL measured it at 0.7 mSv/day and it was measured on the surface of the moon at about 0.9 mSv/day.

In either location the crew would spend most of their time indoors especially if they were establishing a permanent base. As for EVAs, I would think it relatively easy to have the cab shielded with either local materials or some of the base's provisions.

Providing shielding for the habitat should be easy enough. Just telerobotically push regolith onto a layed-out deflated habitat and then inflate it and then push dirt on the sides. According to the following NASA graph, it seems as though shielding with a minimum of about 35 cm of regolith should reduce the GCR exposure by 2/3rds and I would imagine the solar cosmic rays nearly completely. Doing so would buy the crew years with which they could cover their habitat with yet more shielding until radiation became a solved issue.

http://srag.jsc.nasa.gov/Publications/TM104782/shield.jpg

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**Andrew_W** *says:*
September 8, 2015 at 12:42 pm

To me it seemed your intent in this post was to demonstrate that the Martian atmosphere provided enough shielding to enable significant benefits for astronaut activities compared to activities on a body with no atmosphere, eg the Moon or

Phobos.
From here it looks like you've failed: "people would still be exposed to levels of cosmic radiation ranging from 8 Rem to 33 Rem annually during solar maximum and solar minimum conditions. Annual radiation exposure on the lunar surface ranges from 11 Rem to to 38 Rem. So the martian surface still experiences about 87% of the cosmic radiation exposure as the lunar surface."
"MSL measured it at 0.7 mSv/day and it was measured on the surface of the moon at about 0.9 mSv/day"

Can I assume that solar particle radiation levels at Mars orbit (on Phobos) would be lower than at Earth orbit* (on the Moon)? In which case the difference between surface radiation levels on the Moon vs Mars surface have more to do with the distances to the Sun than the blocking of the Martian atmosphere?

* I know the Sun's magnetic field gives some protections in the inner solar system from GCR's, and I know that with thin shielding there's can be an increase in radiation exposure from secondary radiation, I just don't know to what degree it is for each.

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**Chris Stelter** *says:*
September 8, 2015 at 12:54 pm

My point is not so much about average doses but about the acute dose. The key issue for EVAs is acute doses due to solar flares, which the Martian atmosphere does a very good job of shielding compared to free space or a place like the surface of the Moon or Phobos. Also, MSL is higher altitude than Hellas Basin. I am primarily interested in lower altitude sites like Hellas Basin (which is enormous). Mars is huge, so it makes the most sense to consider the most promising places, not the most difficult places like Olympus Mons. Just like on the Moon, where you'd be looking at the conditions near the poles with the ice traps and easy access to consistent sunlight.

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**Chris Stelter** *says:*
September 8, 2015 at 1:19 pm

It should be pointed out that the surface dose for MSL is almost entirely GCR. Solar particle events barely register (part of this is due to the extra-quiet solar minimum), whereas during cruise it measured HUGE radiation doses from solar flares (since it had very little shielding). Moral of the story: with solar flares, a bit of shielding goes a very long way. Mars' atmosphere doesn't shield you much from GCR, but it takes all the sting (acute symptoms) out of solar flares, comfortably so at low-altitude sites like Hellas Basin.

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**Chris Stelter** *says:*
September 8, 2015 at 1:31 pm

…by the way, since MSL landed at the beginning of an especially weak solar minimum and because Mars' atmosphere filters out nearly all solar radiation but passes a lot of GCR, the average surface dose rate during solar max may be much, much lower (half?) than what MSL detects right now. If MSL lasts long enough, we should see this.

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**Andrew_W** *says:*
September 8, 2015 at 1:36 pm

OK, but flares are like rain, if it's too wet, don't go outside, does removing these peaks yield a significant benefit to dwellers on Mars vs on the Moon? I think that even with the atmospheric shielding the Martians will be able to choose to stay inside during flares – and do so.

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**Chris Stelter** *says:*
September 8, 2015 at 1:57 pm

If you're on a long expedition, it'd be pretty inconvenient to have to avoid the outside during a risk of a solar flare. This is

especially true during solar maximum, when the overall dose of GCR would be lower and your colony would probably want to get a lot of work down outside while the dose due to GCR is lower.

Also, on long EVAs, you may not have such an option. You could get "caught outside." Luckily on Mars, this isn't such an issue.

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**Andrew_W** *says:*

September 8, 2015 at 2:11 pm

We could probably go round and round with this one till the cows come home, but my belief is that radiation exposure will be a **major** concern for astronauts on interplanetary missions, and that they won't be risking the significant radiation exposure outside on the surface of Mars during solar storms, and that applies even more so to possible longer term residents.

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**Chris Stelter** *says:*

September 8, 2015 at 2:15 pm

You are not comprehending the difference here. We're talking about several orders of magnitude difference in risk of solar flares between free space and Mars surface (as you can see in the colored graph I added at the end of the post). The difference in average dose is much more modest (just 60% lower on the surface during solar minimum), but the difference in risk of acute doses is huge. I will post graphs later.

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**George Turner** *says:*

September 8, 2015 at 2:28 pm

HZE particles in GCR may be more of a worry than we thought.

What happens to your brain on the way to Mars

The particles cause ionization trails that blast your dendrites, leading to permanent cognitive impairment.

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**Chris Stelter** *says:*

September 8, 2015 at 2:48 pm

This is why we give GCR particles higher quality factors. It's worth remembering that we actually face GCRs here on Earth, in spite of our magnetic field and thick atmosphere. In fact, our atmosphere and magnetic field filter out the lower energy particles, leaving us with a higher proportion of the higher energy particles. Yet we still survive.

I honestly think the radiation problem overall is way overblown. It's scary because it's "radiation," a word that causes a knee jerk reaction of fear in many people (some more than others), and regulatory bodies are prone to compound-conservatism with regard to radiation risks. With moderate countermeasures, the risk due to radiation is less than the risk due to launch and entry.

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**Marcel Williams** *says:*

September 8, 2015 at 6:53 pm

"HZE particles in GCR may be more of a worry than we thought."

Less than 20 centimeters of water would be enough mass to stop the penetration brain damaging heavy nuclei.

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**Chris Stelter** *says:*

September 8, 2015 at 7:44 pm

Marcel: 20cm of water is 20grams/cm^2 of shielding, which is roughly equivalent to the 40grams/cm^2 for the atmospheric shielding in Hellas Basin. I'll put up a graph in an edit that shows this.

**Marcel Williams** *says:*
September 9, 2015 at 10:00 am

The martian atmosphere does appear to be thick enough to stop most of the brain frying heavy ions.

But if you're on the martian surface for a year or more, how frequently would you physically want to explore the martian surface?

Spending 10% of the time exploring the martian surface would reduce your maximum radiation exposure by 90%. But it would still allow you 17 hours of surface time away from your shielded outpost per week. And that's a lot, IMO.

Ironically, while you're inside your shielded outpost, you'd probably get a lot more exploring of the martian surface done by tele-operating mobile rovers and blimps that could also retrieve samples from all over that planet that could be brought back to the outpost for further examination and possible return to Earth.

I also doubt that most permanent colonist would ever want to spend more than 1% of their time outside of the spacious comfort their biodomes per year (88 hours a year). Just because you live near the beach, doesn't mean you want to go swimming and diving every day:-)

Marcel

**Chris Stelter** *says:*
September 9, 2015 at 11:10 am

Agreed. It'll be like January in Minnesota.

**Paul451** *says:*
September 10, 2015 at 9:33 am

Chris,
*"3) That's already decent shielding. However, there's another significant point: That's just the shielding at the zenith of the sky, which ,is the thinnest part! Everywhere else is thicker shielding, near the horizon is MUCH more shielding."*

However, radiation isn't simply blocked or transmitted, it is also *refracted. This means that the radiation coming from directly above (through the thinnest part of the atmosphere) will be scattered and randomised by the time it reaches the surface, creating a relatively uniform "glow" over the entire hemisphere.*

*Simply blocking the zenith isn't sufficient.*

*Weirdly, this even happens with solar storms in free space. There's enough interaction with the existing solar wind to create an anisotropic pattern around your ship. So you can't just aim a shield (say your fuel tank) at the sun and say, "Problem solved".*
*This is yet another one of the unintuitive quirks of space that repeatedly trips people.*

**George Turner** *says:*
September 10, 2015 at 10:38 am

As an aside, if you make a thick helmet you can get a little extra shielding out of it. If you used a 12″ ID aluminum

hemisphere (like a cap) 1.25 inches thick, you get an extra 10 g/cm^2 of shielding for a mass of only 15.3 kg, which on Mars would feel like less than 13 pounds. To get 20 g/cm^2 of extra shielding the helmet would be a little over 2 inches thick with a mass of 29 kg, which would feel like 25 lbs on Mars.

The density calculations are helmet mass divided by inner surface area of the hemisphere. Straight linear path (thickness) is slightly lower, 8.5 g/cm^2 and 14.5 g/cm^2 for the two example helmets.

**Chris Stelter** *says:*
September 10, 2015 at 11:00 am

Paul451:
You're right that secondaries fan out (to less of a degree for the highest energy portions which are traveling at great speed and with high mass), but this is ALSO true of radiation coming in from the Zenith, thus causing the secondaries to travel through more of the atmosphere than they otherwise would. And anyway, this doesn't change the fundamental fact that most of the rays are coming through the solid angle that has to go through at least 40% more atmosphere (and usually much greater than just 40% extra). (EDIT: Also, for cosmic rays coming in at glancing angles, not only does it have to go through more of the atmosphere, a portion of the secondaries can also be scattered into space instead of hitting the ground.) So my point is not strongly affected by your correct observation (although it could effect the details of your shielding strategy).

But your point about the relatively isotropic nature of solar flare radiation is correct. It's not like light which is easily shadowed, because the radiation gyrates /around/ the magnetic field lines in a big spiral, it doesn't merely travel in a straight line along the field lines. A simple shadow shield is thus not sufficient. But the radiation isn't perfectly isotropic, either, and in the case of solar flares, most of the radiation does come in from one side (yes, some of the solar radiation can reflect /back/ along the field lines, but not most of it), so it does make sense to put a thicker shield on the preferred side. And again, this doesn't flow directly along the line-of-sight of the Sun but along the magnetic field lines. (I remember Elon Musk made this mistake one time.)

**gbaikie** *says:*
September 13, 2015 at 10:12 am

==As an aside, if you make a thick helmet you can get a little extra shielding out of it. If you used a 12″ ID aluminum hemisphere (like a cap) 1.25 inches thick, you get an extra 10 g/cm^2 of shielding for a mass of only 15.3 kg, which on Mars would feel like less than 13 pounds. To get 20 g/cm^2 of extra shielding the helmet would be a little over 2 inches thick with a mass of 29 kg, which would feel like 25 lbs on Mars. ==

If you in spacesuit, you going to need cooling, and would use water to cool as they used ice to cool with Apollo. So the water cooler is a hat, rather than a backpack.
On Mars you don't get the evaporating cooling power one gets on the Moon, but water does boil well below the human body heat.
So, a big water hat or Sombrero:
"Giant Sombrero Decorated 65cm Mexican Hats Caps"
http://www.amazon.co.uk/dp/B0041KU4BK/ref=pd_lpo_sbs_dp_ss_1/276-9805163-1603806?pf_rd_m=A3P5ROKL5A1OLE&pf_rd_s=lpo-top-stripe&pf_rd_r=183192JC84PNRBR626XF&pf_rd_t=201&pf_rd_p=569136327&pf_rd_i=B00FFWDCGW

But say 40 cm diameter and assume a average thickness of 5 cm. Which is 6283.2 cubic cm- or 6.3 liters/kg of water. Or say whole thing is 10 kg [22 lbs] which about 7 lbs on Mars. And your head on earth weighs about 10 lb, and on Mars about 3 lbs. So net result is 10 lb head on Mars- though has more mass [inertia].
And like Sombrero it can have more depth above the head, so roughly 10 Cm above the head and say 4 cm average rim. Use plastic for structure.

**Chris Stelter** *says:*
September 17, 2015 at 8:37 am

Gbaikie: Problem is that due to the high neutron flux on Mars (after you get through the atmosphere), the aluminum does you no good and may actually be worse due to neutron activation of the aluminum. It might help in deep space for flares or something, though.

You'd be helped by some polyethylene or even better some liquid diborane (which is quite toxic and explodey), which is somehow both denser (than water and polyethylene) and lower in average atomic mass . Especially if you use Boron-10, which (besides being lighter) is a good neutron absorber.

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**Jeff Wilson** *says:*

September 22, 2015 at 10:25 pm

Sorry for asking a question that is off-topic, but still somewhat related. I'm trying to figure out what the exact solar angle is at any location on Earth on any given day. Is there a formula for it, or is there a pre-existing table? I live in Hawaii, and I want to know when the sun is north or south of me, and the two days of the year when it is directly overhead.

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**MBMelcon** *says:*

September 23, 2015 at 4:23 pm

Jeff, if you know you latitude, an almanac will list solar declension. USGS has one on line.
Try http://www.sunearthtools.com/dp/tools/pos_sun.php or similar sites.
If you are trying to determine solar gain, Sustainable By Design will make a chart for your location and orientation.

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